Lab 3: ACDC converter

Master's programme in Engineering Physics (MEFT), Instituto Superior Técnico,
University of Lisbon

Circuit Theory and Electronics Fundamentals

Ana Almeida 96505
Francisco Simões 96526
Juna Santos 96549

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1 Introduction

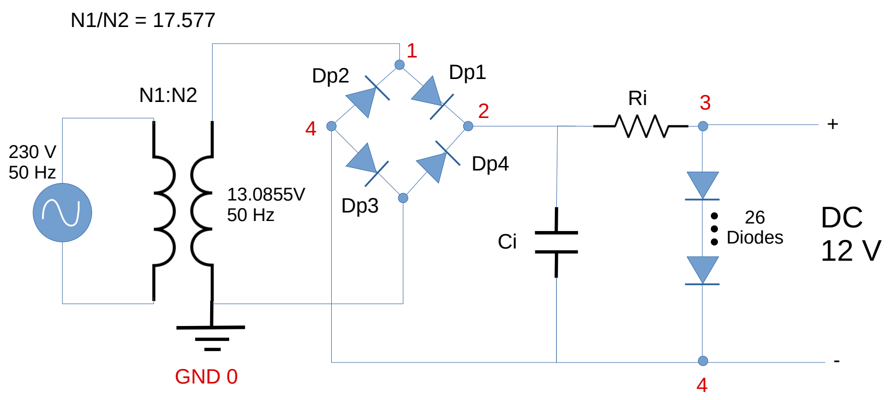
The objective of this laboratory assignment was to simulate and create an acdc converter that would minimize the cost of the components while decreasing the ripple of output. We used Octave for a theoretical analysis of the circuit and Ngspice to simulate it. The values of both analysis are compared at the end of this document. The units of the cost is MU (monetary unit). The merit of our circuit is given by the following expression:

$$M = \frac{1}{cost(ripple(v_0) + average(v_0 - 12) + 10^{-6})} \tag{1}$$

Where:
cost = cost of Resistors + cost of Capacitors + cost of Diodes
cost of Resistor = 1 MU per kOhm
cost of Capacitor = 1 MU per μ F
cost of Diodes = 0.1 MU per diode

The circuit we built is presented in figure 1. The transformer in the left side is considerer to be ideal and the ration N1/N2 is approximated to 17.577. This means that we considered an AC source of 13.0855 V (50Hz) for the rest of the circuit in the right side.

Figure 1: ACDC converter circuit



Components used and respective price are presented in table 1:

Component	Quantity or Value	Cost
Resistor (Ri)	13.6 kOhm	13.6 MU
Capacitor (Ci)	8 uF	8.0 MU
Diodes (Dp1-Dp30)	30	3.0 MU
Total	-	24.6 MU

Table 1: Electrical Components used and respective cost in MU

2 Theoretical Analysis

The circuit incorporates three main elements, which are a transformer, an envelope detector, and a voltage regulator.

2.1 Envelope Detector

The transformer converts the initial voltage, 230V, to 13.0855V, this last value was taken from ngspice simulation. The envelop detector incorporates one capacitor and a bridge rectifier. The function of the bridge rectifier, which consist of four diodes, is to convert the alternating current (AC) input that comes from the transformer into a positive current output, with double the frequence. To achieve this it is only necessary to get the absolute value of Vs

$$abs(Vs) = abs(13.0855cos(wt)) \tag{2}$$

The purpose of the capacitor is to slow the change and flatten the curve.

Knowing that when t $<$ t_{OFF}

$$t_{OFF} = \frac{1}{w}atan(\frac{1}{wRC}); \tag{3}$$

the voltage of the envelope is the absolute value of Vs and when t $>$ t_{OFF} the envelope voltage is given by

$$v = 13.0855cos(wt_{OFF})exp(-\frac{t - t_{OFF}}{RC}); \tag{4}$$

we are able to compute the envelope voltage.

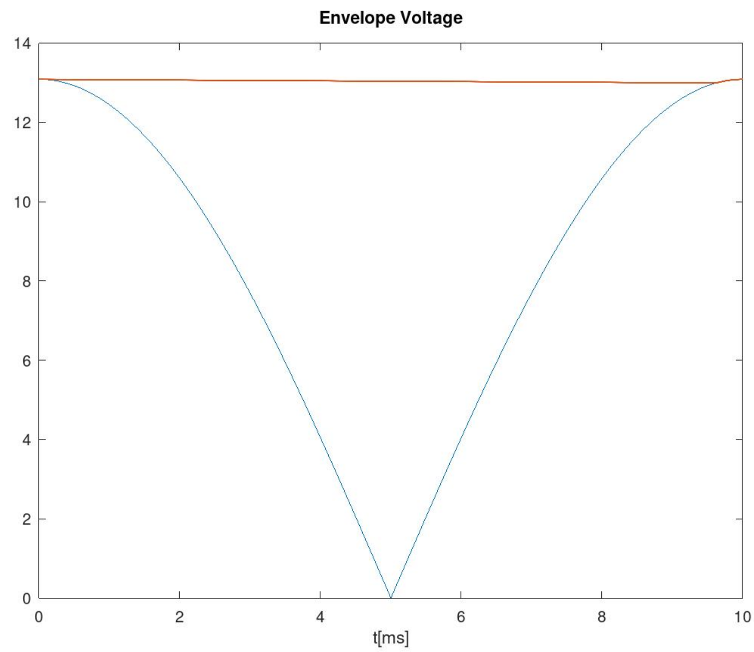


Figure 2: Evolution of the voltage at the ends of the capacitor in one half period

2.2 Voltage Regulator

In order to minimize the ripple effect in the output desired DC voltage, we added a resistance R in series with 26 diodes. In order to achieve a voltage drop, we considered non ideal diodes with an associated resistance.

Analysing this half of the circuit using incremental analysis, the diodes are simplified to their internal resistor r_d. Using $V_T = 23.35mV$, $I_s = 10^{-14}$ and $\eta = 1$, we calculated

$$r_d = \frac{\eta V_T}{I_s e^{\frac{V_D}{V_T \eta}}} \tag{5}$$

Because the diodes all in series with each other the total resistance R_d is equal to $26 * r_d$ and the total voltage drop of the diodes can be analysed through a voltage divider, $V_d = \frac{R_d}{R_d + R} V_{env}$.

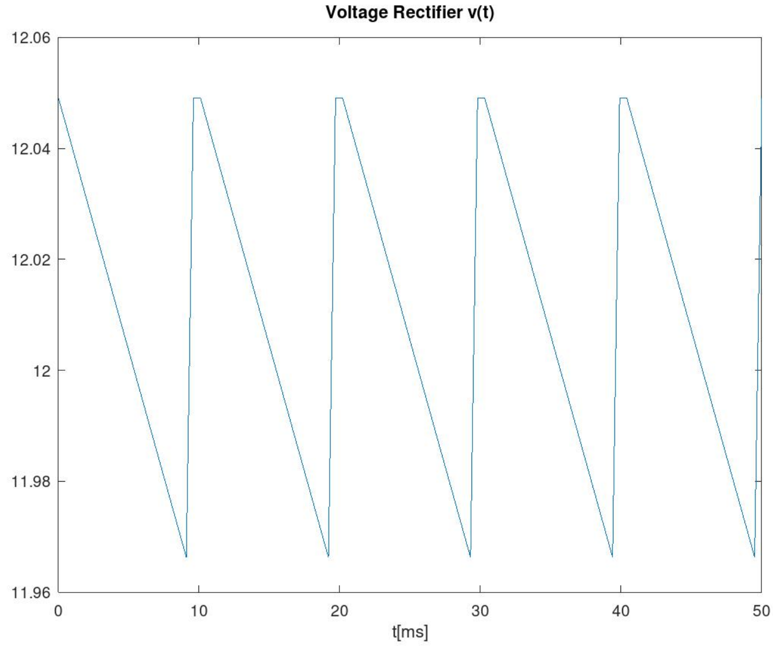


Figure 3: Evolution of the voltage at the ends of the 26 diodes during 5 semi-periods

2.3 Voltage Ripple

The voltage ripple is a consequence of the difficulty in converting a sinusoidal wave signal in a constant one. A bigger capacitance value in the capacitor C_i lowers the current flow over time and so, it flattens the capacitor curve, allowing a smaller value for the ripple.
For a small ripple due to a good envelope regulator, t_{off} can be approximated to the begining of the oscilation period and t_{on} can be aproximated to half a period, and so, the voltage ripple can be approximatly calculated by $V_r = V_s(1 - e^{\frac{-T}{2RC}})$. Therefore, a bigger time constant allows a smaller ripple.

Quantaties	Volts
average	1.200972e+01
ripple	8.990121e-02
deviation	9.718317e-03

Table 2: Value of DC Output (V). Ripple Value (V).

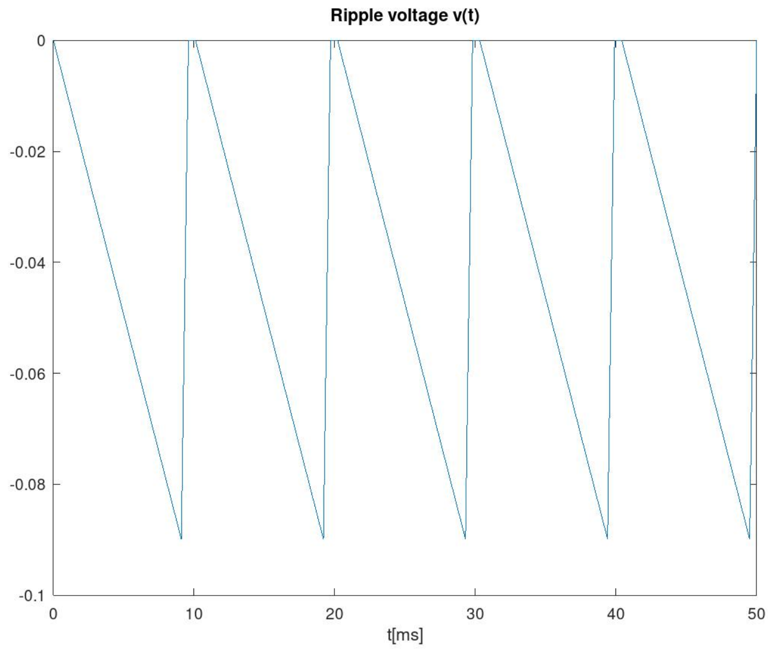


Figure 4: Oscilations in the final voltage - ripple

3 Simulation Analysis

The Ngspice Software was used to simulate the circuit. We used Ngpice's transient analysis mode to get v3(t)-v4(t), the dc output nodes, during 200 ms in order to observe 10 periods, take note that the frequency is 50Hz. The initial time is 10 seconds in order to obtain the stationary part of the output, ignoring the trasient first part. We had to set TMAX in transient analysis in ngspice, this tells the SPICE engine the max step it is allowed to take, but if it needs to take smaller steps it will. The TMAX value was set to be 2e-4 in order to obtain at least 1000 points during the 200ms. The table 3 presents the values obtained. The figures 5, 6 and 7 present the dc ouput, the envelope and the deviation value obtained in ngspice.

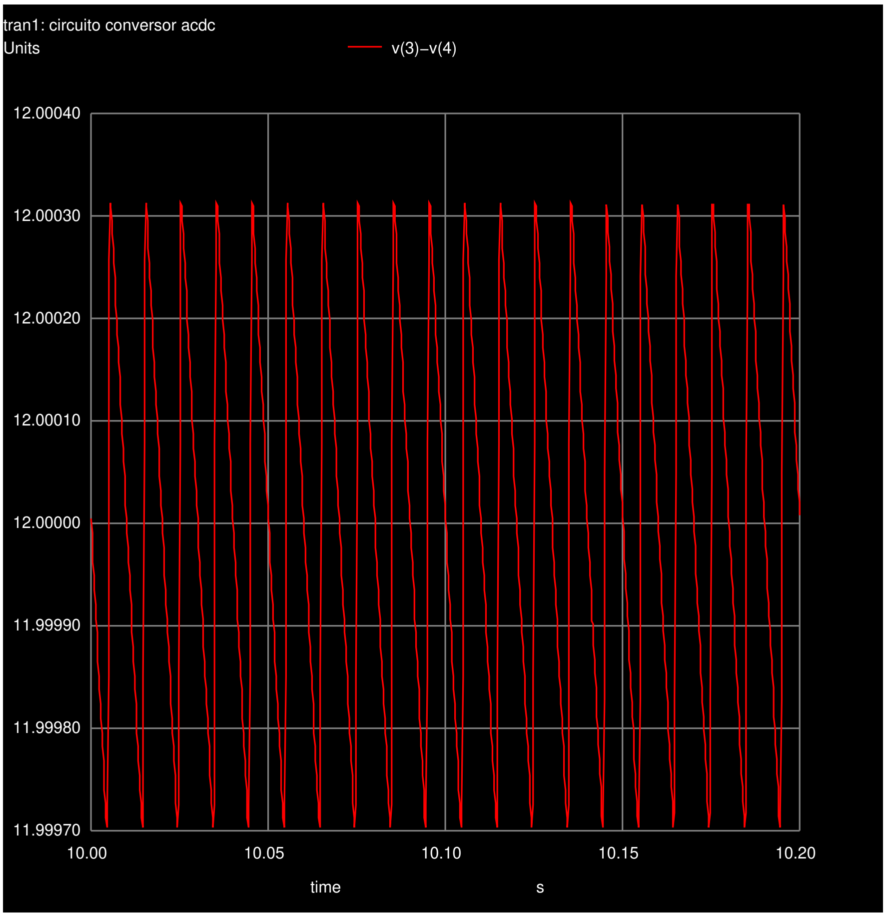
3.1 Values obtained

Quantities	Volts / MU
average	1.200001e+01
deviation	8.137661e-06
ripple	6.098120e-04
cost	2.460000e+01
merit	6.567644e+01

Table 3: Average Voltage Value of DC Output (V). Ripple Value (Max-Min) (V). Cost of Circuit (MU). Merit of Circuit.

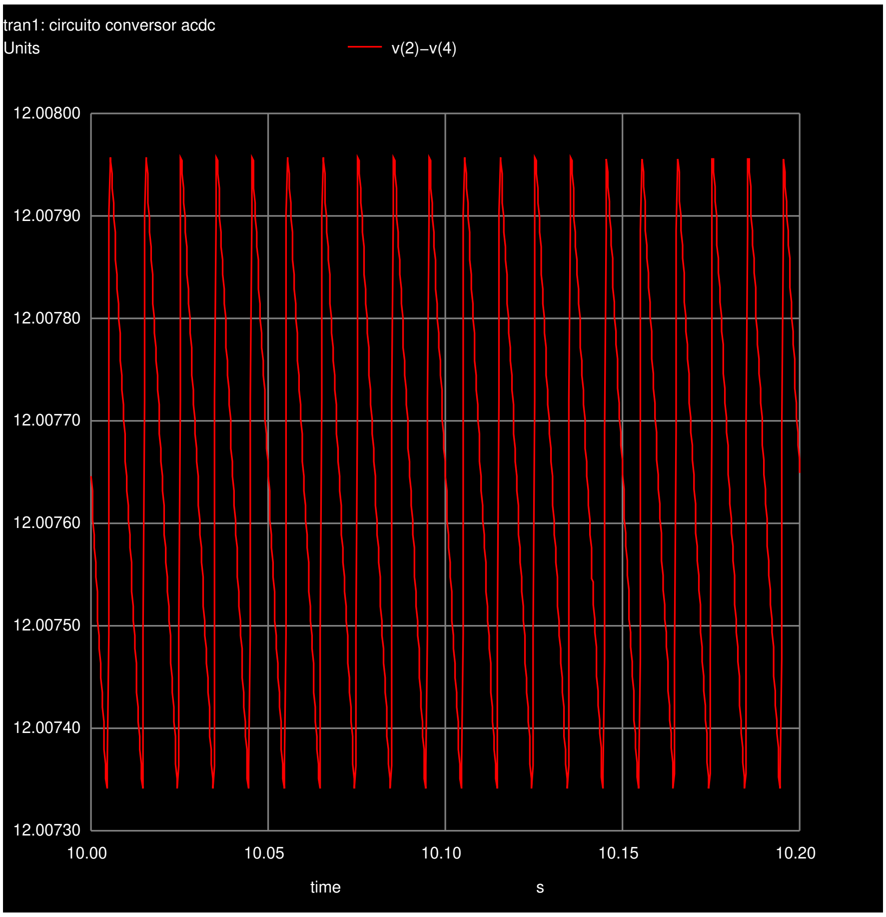
3.2 DC Output

Figure 5: DC Output for 200ms



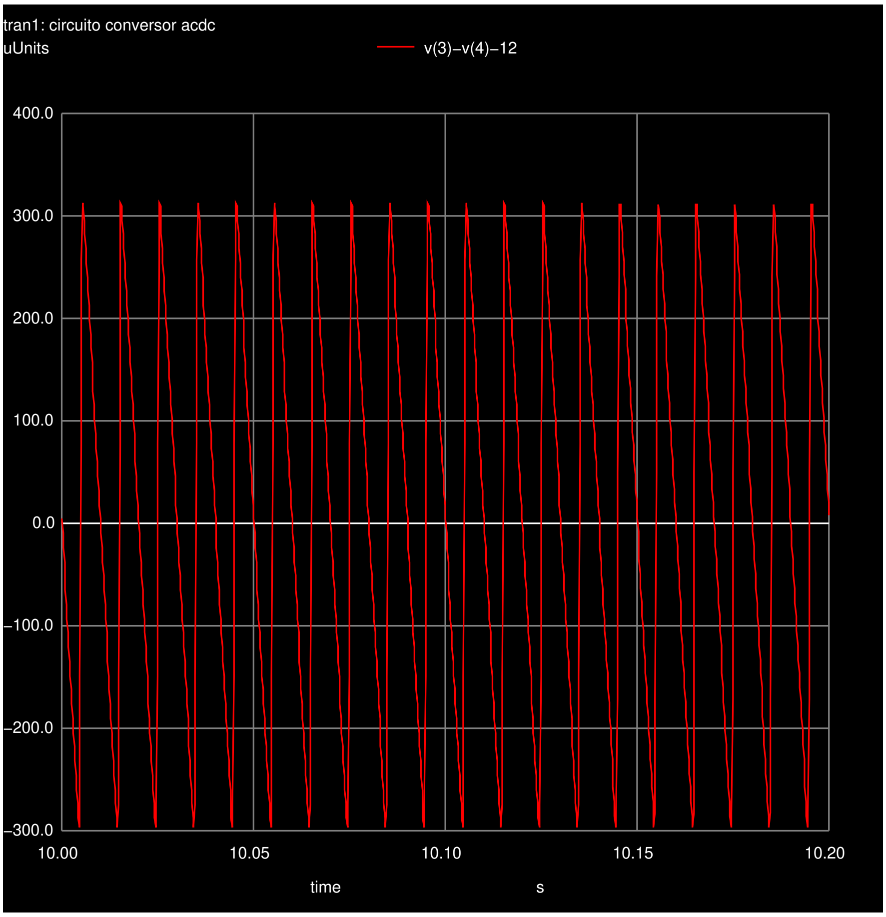
3.3 Output of the Envelope Detector

Figure 6: Output of the Envelope Detector for 200ms



3.4 Ouput Deviation

Figure 7: Output AC component + DC deviation for 200ms in uVolts



4 Values and comparison

The value obtained for the exit DC Voltage (tab. 2) differs from the one obtained in the simulation (tab. 3) by only $9.71mV$. Although we used the same number of diodes and the same resistance value for the resistor R, we still weren't able to perfectly synchronize the two. Since the model of the diodes is different in the two programs, that must be the reason for the difference between the voltage regulator effect. The major difference is between the ripple in both theoretical and simulation analysis and this is due to the approximation explained in section 2.3 when calculating the value for the ripple.

Quantities	Volts / MU
average	1.200001e+01
deviation	8.137661e-06
ripple	6.098120e-04
cost	2.460000e+01
merit	6.567644e+01

Table 4: **Simulation** Average Voltage Value of DC Output (V). Deviation value (V). Ripple Value (Max-Min) (V). Cost of Circuit (MU). Merit of Circuit.

Quantaties	Volts
average	1.200972e+01
ripple	8.990121e-02
deviation	9.718317e-03

Table 5: **Theoretical** Value of DC Output (V). Ripple Value (V). Deviation value (V).

5 Conclusion

In this laboratory assignment the objective of simulating an ACDC converter has been achieved. Time analysis has been performed both theoretically using the Octave maths tool and by circuit simulation using the Ngspice tool. The results obtained in Octave and Ngspice matched each other with a considerable error. Graphically there are little distinctions between the plots made in ngspice and octave. The differences are due to the fact that the diode models weren't compatible in the two programs. In order to solve the complex non linear equations of the theoretical analysis some aproximations were made, that were explained in the Analysis Section. We also should note that in ngspice simulation we had to made the transient analysis starting at 10 seconds so we could observe only the stationary part. Right now we are able to build our own AC adapter to charge our devices.